

**RESTORING FOREST ECOSYSTEMS**

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**INTRODUCTION**

Forest cover has declined globally, from an estimated 6.1 billion hectares (ha) of "original" forest to the present 3.45 billion ha (Krishnaswamy and Hanson 1999). The greatest loss in cover has occurred in Asia-Pacific, Africa, and Europe (all more than 60 percent loss of forest cover). Losses in North America are relatively low (25 percent), while Latin America (Central and South) has lost over 30 percent of the original forest cover (Figure 1). Nevertheless, the area in forest plantations is only 135 million ha, although increasing (Kanowski 1997).

Efforts worldwide to restore forest ecosystems seek to counteract centuries of forest conversion to agriculture and other uses. Forest restoration in the broad sense is widespread, although there is no agreement on what constitutes restoration. Market forces, changing trade policies, and agricultural incentive programs drive conversion of cleared land back to trees.

Afforestation, the practice of regenerating forests on land deforested for agriculture or other uses, is occurring at an intense pace in the Lower Mississippi Alluvial Valley (LMAV) of the southern United States. Today, as in the past, forest cover competes with other uses of land. Recent estimates of the potential for afforestation in the LMAV suggest that as many as one million ha may be planted over the next decade (Stanturf et al. 1998, King and Keeland 1999, Stanturf et al. 2000,).

Objectives of this chapter are (1) to place afforestation efforts in the LMAV into a global context of forest restoration by drawing parallels to work in

other countries; (2) to summarize available information on afforestation techniques used to restore bottomland hardwood ecosystems; and (3) to document what is known about the effects on ecosystem functions. Most of the ideas for this chapter come from the authors of papers presented at the Conference on Sustainability of Wetlands and Water Resources, held May 23-25, 2000 at the University of Mississippi (Burbridge and Hellin In Press, Conner et al. In Press, Davis et al. In Press, Gardiner et al. In Press, Hamel et al. In Press, Lockaby and Stanturf In Press, Madsen et al. In Press, Stanturf In Press, Warren et al. In Press). Furthermore, portions of this chapter were extracted from Gardiner et al. In Press and Stanturf In Press.

#### **THE LOWER MISSISSIPPI ALLUVIAL VALLEY CONTEXT**

The LMAV has undergone the most widespread loss of bottomland hardwood forests in the United States. Besides the extensive loss of forest cover by clearing for agriculture, regional and local hydrologic cycles were changed drastically by flood control projects that separated the Mississippi River and its tributaries from their floodplains (Sharitz 1992, Shankman 1999, Stanturf et al. 2000). The LMAV is regarded as one of the most endangered ecosystems in the United States (Noss et al. 1995). Bottomland systems across the southern United States provide habitats for breeding populations of Neotropical migratory birds as well as staging grounds for these birds during migration. The southern United States is at risk for significant loss of aquatic diversity, particularly native fishes, freshwater mussels, and crayfishes. The Environmental Protection Agency has identified the Yazoo-Mississippi basin as an area of significant concern for surface and ground water quality (EPA 1999). In response to concerns for wildlife habitat and water quality protection, the LMAV has been targeted for the most extensive forest restoration effort in the United States.

#### **The Need for Restoration**

Before European contact, bottomland hardwood forest occurred on 8.5 to 10.1 million ha in the LMAV (The Nature Conservancy 1992), although actual forest cover may have been less because of agricultural use by Native Americans (Hamel and Buckner 1998). Fully 96 percent of subsequent deforestation in the LMAV has been by conversion to agriculture (MacDonald et al. 1979, Department of the Interior 1988). About one half of the original forests were cleared between the early 1800s and 1935 (Figure 2). Flood control projects straightened and deepened rivers, drained swamps, and encouraged the extension of forest clearing to lower, wetter sites. The most recent surge in deforestation occurred in the 1960s and 1970s when rising world soybean (*Glycine max* (L.) Merrill) prices made it profitable to convert additional area to agriculture (Sternitzke 1976). However, the passage of "Swampbuster" provisions in the 1985 Farm Bill has minimized further clearing of forested wetlands for agriculture (Shepard et al. 1998).

The remaining 2 million ha of bottomland hardwood forests in the LMAV occur mostly (over 95%) in Louisiana, Mississippi, and Arkansas (The Nature Conservancy 1992). Thirty-one percent of this area is found in the Atchafalaya Basin of Louisiana, which constitutes the largest remaining contiguous block of bottomland forests (The Nature Conservancy 1992). Much of the remaining bottomland hardwoods in the LMAV lies between the mainline levees of the Mississippi River and is referred to as batture land.

#### **Restoration Practice**

Actions on federal land and federal incentive programs drive restoration in the LMAV, although states also have restoration projects on public land (Newling 1990, Savage et al. 1989). The dominant goal of all restoration programs in the LMAV, whether on public or private land, has been to create wildlife habitat and improve or protect surface water quality (King and Keeland 1999). In practice, this means afforestation of small areas (usually no more than 120 hectares) within a matrix of active agriculture. While we

know how to afforest many sites (Stanturf et al. 1998), recent experience with the Wetlands Reserve Program (WRP) in Mississippi illustrates the difficulty of applying this knowledge broadly (Stanturf et al. 2001a). Currently, restoration on public and private land is planned for 200,000 ha in the LMAV over the next decade (Table 1) but as much as 1 million ha may be available (Stanturf et al. 2000).

#### **TERMINOLOGY**

What constitutes restoration can be confusing as the term is often used indiscriminately. It is helpful to consider the dynamic relationship between degrading and restoring processes in light of two dimensions, changes in land cover, land use, or both. If we consider the undisturbed, idealized natural mature forest as a starting point (Figure 3), then conversions to other land uses such as agriculture or pasture are through deforestation. Relatively frequent but moderate disturbance (plowing, herbicides, grazing) maintains the non-forest cover.

Similarly, a change in both land cover and land use occurs when forests are converted to urban uses, flooded by dams, or removed along with topsoil/overburden in mining and extractive activities. Such drastic conversion usually involves severe disturbance and is maintained more or less permanently by structures more than by cultural activities (Figure 3).

Even-aged harvesting of mature forest in a sustainable manner is a change of land cover but not land use. A new, young forest will result from natural regeneration or by reforestation (i.e., planting trees in a harvested area). Unsustainable harvesting without securing adequate regeneration, such as high-grading (many diameter-limit harvests or selective harvesting), degrades stand structure or diversity. Forest also can be degraded by pollutant loading, outbreaks of insects or diseases (especially exotics), invasion by aggressive

exotic plants, or by disasters such as hurricanes or wildfires. In all these instances, intervention to restore species diversity, stand structure, or productivity can be termed rehabilitation (Figure 3).

Given sufficient time and cessation of disturbances, agricultural land as well as urbanized land will revert to forest, if that is the potential natural vegetation as set by climate. Natural reversion to forests after abandonment, albeit secondary or even degraded forest types, will require a few decades or centuries. Human intervention, however, can accelerate the reversion process. Afforestation of agricultural land may consist of simply planting trees, although techniques that are more intensive are available. Reclamation of urbanized land usually requires more extensive modification, which may include stabilization of spoil banks or removal of water control structures, followed by tree planting. Because severe degradation may limit the possibilities for reclamation, these practices are sometimes called replacement (Bradshaw 1997).

Generally, restoration connotes transition from a degraded state to a former "natural" condition. All restorative activities described (reforestation, rehabilitation, afforestation, and reclamation) have been called forest restoration, but none of these would qualify as true restoration to the purist (Bradshaw 1997, Harrington 1999). In the narrowest interpretation, restoration requires a return to an ideal natural ecosystem with the same species diversity, composition, and structure of a previous ecosystem (Bradshaw 1997) and as such is probably impossible to attain (Cairns 1986). Pragmatically, a broad definition of forest restoration would include situations where forest land use as well as land cover are re-established (afforestation or reclamation) or where a degraded forest is returned to a more "natural" condition in terms of species composition and stand structure

(rehabilitation). This is the approach adopted in this chapter.

Examples of forest restoration abound (Table 2) and those in Northern Europe illustrate the diversity of conditions that may occur (Madsen et al. In Press). Nordic forests provide diverse examples of afforestation and rehabilitation. In Iceland, afforestation on barren and degraded land aims to restore birch (*Betula* spp.) woodlands, which covered more than 25 percent of the land area at the time of settlement in the tenth century (Sigurdsson 1977). In contrast, afforestation in other Nordic and Baltic countries occurs on fertile farmland. Even so, the aims of afforestation differ between these countries. In Finland, Sweden, and Norway afforestation is limited to replacing small-scale, inefficient agriculture. In Estonia, agricultural property has been returned to descendants of the former landowners. Many of these "new" landowners lack knowledge or experience with agronomy. Thus, forestry may provide these landowners with a low-cost land-use alternative. As a result of afforestation, a significant increase in Estonian forestland is expected. The afforestation program in Denmark emphasizes sustainability, nature conservation, and biodiversity; with provisions to protect ground water, improve recreational value of the landscape, and reduce agricultural subsidies (Madsen et al. In Press). The Danish government intends to double the nation's forested area within one tree rotation, about 100 years.

Forestry in the Nordic countries traditionally has traditionally emphasized conifer management for timber and pulp. Conifers are favored because of their high productivity and low cultivation costs. Concerns for ecological sustainability, nature conservation, and sustainable land use have risen over the past two decades, while prices for softwood timber have fallen. Additionally, some conifer species are prone to windthrow on certain sites. These problems have led landowners to an increased interest in managing broadleaf species and natural regeneration practices (Larsen 1995). Broadleaf tree species are being considered for afforestation of former agricultural

land, and for conversion (rehabilitation) of conifer plantations on better soils in Denmark, southern Sweden, Germany, the United Kingdom, and the Republic of Ireland (Table 2).

#### **PLANTATION FORESTRY AS A RESTORATION MECHANISM**

It should be self-evident that the first step in restoring a forest is to establish trees, the dominant vegetation. Although this is not full restoration in the sense of Bradshaw (1997), it is a necessary step and far from a trivial accomplishment (Hamel et al. In Press, Stanturf et al. 1998, Stanturf et al. 2001a). Nevertheless, many people object to traditional plantations on the grounds of aesthetics or lack of stand and landscape diversity. The correct ecological comparison, however, is between the forest plantation and intensive agriculture, rather than between the forest plantation and a mature natural forest (Stanturf et al. 2001a). All forest alternatives provide vertical structure, increased plant diversity, wildlife habitat, and environmental benefits. Kanowski (1997) argued for a dichotomy in concepts of plantation forests, between traditional industrial plantations established for fiber production and complex plantation systems established to maximize social benefits other than wood. Perhaps some restoration goals can be met better by developing a concept of complex plantations that retain economic and logistic advantages of simple plantations.

#### **Characteristics of Simple Plantations**

Simple plantations are single purpose, usually even-aged monocultures that can produce up to ten times more wood volume than natural forests (Kanowski 1997). Simple plantations, nevertheless, provide multiple benefits when compared to alternatives such as continuous agriculture. For example, they may satisfy sustainability criteria if managed well. Advantages of simple plantations include that they can be established with proven technology, their management is straightforward, and they benefit from economies of scale. Simple

plantations may be preferred if financial return is the primary objective of a landowner (Stanturf et al. 2001a). However, complex plantations that provide greater social benefit can be established at a reasonable cost. The additional cost may be as little as a 10 percent reduction in timber returns (Kanowski 1997) or at a net financial gain to the landowner (Stanturf and Portwood 1999).

#### **Complex Plantations Characteristics**

**Association with other land uses**--Objections to forest plantations are often cast in terms of aesthetics. The "sharp" boundary between a plantation and other land uses is objectionable, as is the uniformity of trees planted in rows. To integrate the plantation with other land uses, sharp edges can be "softened" by fuzzy or curved boundaries. Where plantations are established on small farm holdings, agroforestry systems such as intercropping can blend land uses. Additionally, forested riparian buffers can be established in as plantations in agricultural fields. These plantation buffers can protect water quality by filtering sediment, nutrients, and farm chemicals, and they may limit access by livestock to stream banks. Riparian buffers increase landscape diversity and can serve as corridors between patches of fragmented forests. In floodplain landscapes such as bottomland hardwoods, areas of permanently saturated or inundated soil (respectively, moist soil units and open water areas) are common and diversify the interior of plantations.

The uniformity of plantation rows can be overcome in several ways. Perhaps the simplest technique is to offset rows. Uniform spacing between rows and between seedlings within a row is common, resulting in a square pattern. Such a pattern is necessary only if required for post-planting operations such as disking, or if maximizing stocking is desired. Rows can be offset to produce a parallelogram instead of a square. Alternatively, plantations can be

planned with a recreational viewer in mind so that the view from trails and roads is always oblique to the rows, thereby escaping notice. Still, once the canopy reaches sufficient height that ground flora and midstory plants can establish, many plantations take on the appearance of natural stands, at least to the casual observer. This is especially the case following manipulation of structure by thinning.

**Species composition and vegetation structure**--A more serious objection to plantations is the lack of diversity, in terms of species composition and vertical structure. Simple plantations typically are not as diverse as natural stands, at least for many years. Foresters have devised several methods to establish multiple species stands. For example, planting several blocks of different species in a stand, or even alternate rows of different species is possible and creates some diversity at the stand level. Distribution, however, remains more clumped than would be typical of a natural stand.

Other methods are available for establishing mixed species stands. For example, nurse crops of faster growing native species (Schweitzer et al. 1997) or exotics (Lamb and Tomlinson 1994, Ashton et al. 1997) may be used to facilitate establishing slower-growing species. In this approach, there is no intention of retaining the nurse crop species through the rotation of the slower growing species (this could also be termed relay intercropping). While the nurse crop method has many advantages, and in the short-term provides species diversity and vertical structure, these characteristics may decline once the nurse crop is removed. The challenge is to develop methods for establishing several species in intimate mixtures. Such methods must account for species growth patterns, relative shade tolerances, and competitive abilities to avoid excessive mortality during the self-thinning or stem

exclusion stage of stand development.

Vertical structure is an important feature of forests for wildlife habitat (DeGraaf 1987, Twedt and Portwood 1997, Hamel et al. In press,). Early stages of stand development, whether in natural forests or plantations, are characterized by low light availability in the understory. In most restoration forests, understory and midstory development does not occur for many years, until overstory crowns differentiate. Annual disturbance while in agriculture removed buried seed and rootstocks of native plants and low light levels in the young forest preclude understory development from invaders. Land managers can intervene by planting understory species, but guidance on methods, planting density, or probable success rates is lacking. As indicated above, relay intercropping provides vertical structure for a portion of the rotation. Natural dispersal into gaps may encourage understory development, whether gaps are created by thinning or left during planting (Allen 1997, Otsamo 2000). The critical factor limiting understory development by natural invasion is whether there are seed sources for understory plants within dispersal range (Johnson 1988, Chapman and Chapman 1999).

#### COMMON CHALLENGES IN RESTORATION

The challenges of forest restoration in different countries are surprisingly similar (Kanowski 1997): overcoming site degradation/limitations; prescribing appropriate species; and applying cost-effective establishment methods. Three steps are key to planning forest restoration: (1) understanding current conditions (the given conditions, a starting point); (2) clarifying objectives and identifying an appropriate goal (the desired future condition); and (3) defining feasible actions that will move toward the desired condition. In most cases, the forester has several options for intervening, as there are multiple silvicultural pathways toward the desired future condition. The choice of

intervention affects the financial cost, the nature of intermediate conditions, and the time it takes to achieve the desired condition. It is imperative that silvicultural decisions are made with clear objectives in mind and with an understanding of the probability that a particular intervention will be successful.

### **Overcoming Site Limitations**

Site potential, and whether it has been degraded, sets limits on what can be achieved by intervention. Site potential refers to the combination of relatively unchanging physical factors which affect species composition and stand vigor. Soil and landform characteristics determine moisture availability, aeration, and fertility. In wetland forests, hydroperiod characteristics are important (flood frequency, seasonality, duration, and depth). Site potential is not immutable, however, and can be influenced positively or negatively by changes in land cover or land use. Existing forests in need of rehabilitation may have become degraded by past mismanagement such as timber high grading, fire suppression or holding water late into the growing season in greentree reservoirs. In other cases, hydroperiod alterations, hurricanes, severe windstorms, floods, or insect outbreaks may degrade the stands but not usually the site. On the other hand, previous land use may have degraded site conditions, especially for afforestation and reclamation projects. Specific conditions may vary from soil erosion or salinization in which soil chemistry and physical structure are inhospitable to native trees, to lowered fertility from continuous cropping (e.g., Whalley 1988). In some cases, land becomes available for restoration because the previous land use was unsustainable.

An extreme example of an unsuitable land use practice leading to site

degradation and creating the need for forest restoration can be found in the mangrove (*Rhizophora* spp., *Avicennia* spp., and others) forests of Asia (Burbridge and Hellin, In Press). Aquaculture is an important source of income, employment, and exports in many of the world's coastal regions. Extensive aquaculture has been a sustainable part of coastal land and water use for many centuries in Asia. The rapid expansion into mangrove forests of semi-intensive and intensive shrimp aquaculture, often poorly planned and managed, has created significant adverse environmental, economic and social effects. Unnecessary destruction of coastal wetland forests for non-sustainable aquaculture production has occurred in extensive areas of many of the poorer developing nations such as India, the Philippines, and Indonesia (Burbridge and Hellin, In Press). Following abandonment of fishponds, because of acid sulfate potential soils, reclamation projects are necessary to restore mangrove forests (Burbridge and Hellin, In Press).

Human-induced disturbances are overlain on the natural disturbance regime in the landscape. Coastal Plain swamp forests of the southern United States, for example, exist with windstorms as normal, episodic events (Conner et al. 1989). Recent hurricanes such as Hugo (in 1989) in the southeast Atlantic Coastal Plain and Andrew (in 1992) in the northern Gulf caused extensive damage to forests in their paths. Such damage may be especially severe to shallow-rooted hardwoods with large crowns that are common on alluvial floodplains (Sharitz et al. 1993). Regeneration in hurricane-damaged areas may be limited if natural hydrological patterns have been altered.

Rehabilitation problems in swamp forests dominated by baldcypress (*Taxodium distichum* (L.) Rich) and water tupelo (*Nyssa aquatica* L.) or Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.) illustrate the critical constraint imposed by hydroperiod (Conner and Buford 1998, Conner et al. In Press). Floodplain communities are adapted to a predictable flood pulse, and alteration of the timing, duration, or magnitude of this flooding reduces

diversity and productivity (Junk et al. 1989). Human activities have inextricably altered the hydrologic regime of most alluvial floodplains in the United States (Dynesius and Nilsson 1994, Poff et al. 1997, Ligon et al. 1995, Shankman 1999). Dams reduce the frequency, magnitude, and flashiness of downstream flooding, often extend the length of time the floodplain is inundated, and may change seasonality of peak flows, reduce the rates of erosion and sedimentation (in silt laden systems). Channelization and canal building, with associated levees or spoil banks, often impound water permanently over large areas of swamplands (Conner and Day 1989). Because many swamp areas are permanently to nearly permanently flooded, natural regeneration is negligible (Conner et al. 1989), and planting is difficult.

Another aspect of flooding that should be considered for coastal swamp forests in the United States is sea level rise and resulting increases in salinity (Conner and Day 1988, Conner and Brody 1989). Although baldcypress and water tupelo can survive extended and even deep flooding (Hook 1984, Keeland and Sharitz 1995), they seem incapable of enduring sustained flooding by water with salinity levels greater than 8 ppt (McLeod et al. 1996, Conner et al. 1997). Atlantic white-cedar is another coastal species that is very intolerant of salinity (Little 1950).

The cause of site or stand degradation should be identified and whether the degradation is still occurring. For example, alteration of a site by changed hydroperiod poses several questions. Can the hydroperiod be restored or the effects of alteration somehow mitigated? Should the restoration effort target a vegetation assemblage adapted to present hydroperiod and site conditions? Hydroperiod alterations caused by flood control projects, dams, or highway construction tend to be irrevocable, at least in the short-term. Flooding caused by beaver (*Castor canadensis* Kuhl) dams, however, can be reduced by removing the dam, but continued management of beaver population levels will be required to avoid recurring problems. The guiding principle for the forester

should be to rehabilitate or restore in accordance with existing conditions, unless alteration is feasible, affordable, and within the control of the forester.

### **Appropriate Species**

Most restoration efforts favor the use of native species although there are situations where exotic species are preferred. In the Tropics, population pressures and land scarcity may require that restoration include species that provide early economic returns (Grainger 1988, Parrotta 1992, Islam et al. 1999), and native forest species may be unsuited for degraded sites. Fast-growing exotic species can be used to alter site conditions enough for native species to thrive (Ohta 1990, Parrotta et al. 1997). Nevertheless, the potential of native species may be overlooked in some cases because of lack of knowledge (Butterfield and Fisher 1994, Fisher 1995, Knowles and Parrotta 1995).

The perception of what constitutes "native" species or communities may be contentious. Some fast-growing species may be native but considered undesirable by portions of the public or by agencies. For example, some hold an aversion to planting pine (especially loblolly pine, *Pinus taeda* L.) rather than broadleaves in the southern United States, and some disapprove of planting eastern cottonwood (*Populus deltoides* (Bartr.) ex Marsh.) in the LMAV. Furthermore, species on the approved list for afforestation programs may be native to the area but not to the particular site. In the LMAV, for example, extensive hydrologic changes have allowed planting of oak (*Quercus* spp.) in greater proportion than is thought to have been in the forests prior to European settlement (Figure 4). Even documenting the composition of the pre-disturbance forested landscape can be difficult and contentious (Hamel and Buckner 1998, Stanturf et al. 2001a).

Alluvial floodplain forests exhibit high species richness and spatial diversity of vegetational communities (Meadows and Nowacki 1996, Kellison et al. 1998). More than 70 tree species are endemic to bottomland hardwood forests of the LMAV along with numerous vines, shrubs and herbaceous species (Putnam et al. 1960, Carter 1978, Tanner 1986). A wide array of edaphic and hydrologic conditions sculpted by the erosional and depositional processes of rivers provide the foundation for vegetational diversity in alluvial floodplains. Site types range from permanently inundated sloughs with very poorly drained, heavy clay soils to rarely inundated ridges of well-drained, sandy loams (Stanturf and Schoenholtz 1998). Associations of tree species with the various site types have been well established since the early 1900s (Putnam et al. 1960, Tanner 1986, Meadows and Nowacki 1996). Thus, it follows that initial and long-term afforestation success; trajectory of stand development, site productivity, and future management opportunities and costs will be determined largely by the suitability of the species assigned to a given site.

An open question is to what extent should the manager today consider the possible effects of global climate change in choosing appropriate species to plant. Global Circulation Models used by policymakers yield very different results for the southern U.S. at the scale of the forest stand. Nevertheless, managers contemplating long-rotations may want to hedge their bets by planting species adapted to drier conditions on upland sites. In bottomlands, the situation is more complicated. Projected rising sea level will not only inundate coastal forests but also cause a rise in the base level of rivers in the region, changing the hydrologic regime of many sites.

#### **Effective Establishment Methods**

Choosing species appropriate to the site and management objectives of the landowner is an important first step in restoration. Choice of stock type and proper handling are important as well as adequate site preparation and post-

planting practices such as weed control. High survival is needed to insure adequate stocking (seedling density) and to minimize costs, especially where seedling costs are high (e.g., Scandinavia; Madsen et al. In press). Survival rates in industrial plantations set the benchmark, and are commonly 80 percent to 90 percent. However, it may be unreasonable to expect such high survival in many restoration programs (King and Keeland 1999), as the knowledge base may be insufficient due to limited research, lack of practical experience, or untrained available labor (Gardiner et al. In Press).

#### **RESTORATION OF BOTTOMLAND HARDWOODS**

##### **Matching Species to Site**

Several sources of information are available to assist the afforestation forester in the LMAV with species-site prescriptions. These relationships are documented by research of Baker (1977), Krinard and Johnson (1985), Dicke and Toliver (1987), Williams et al. (1993), and Stine et al. (1995). Practical guidelines are available (Baker and Broadfoot 1979, Broadfoot 1976). In addition, soil can be sampled and analyzed for limiting physical and chemical properties related to texture and drainage classes, plow pan development, nutrient deficiencies, or other factors that impair nutrient uptake such as high pH. Furthermore, land managers often survey adjacent forested stands to determine availability of seed sources of desirable species. Such information can be used in conjunction with available literature to make informed decisions on species assignments (Groninger et al. 1999). In practice, though, availability of planting stock is probably the most prevalent factor driving species assignments on afforestation sites. Fewer than 25 of the 70 plus native bottomland hardwood species are available through established commercial nurseries on a yearly basis. However, some nursery managers will custom raise seedlings of other species if contracted.

##### **Site Preparation**

Site preparation is used to condition the seed or seedling bed, decrease competing or undesirable vegetation (such as exotic pests), reduce herbivore habitat, improve nutrient availability, and improve access on the site for the planting operation (Baker and Blackmon 1978, Kennedy 1981a, Kennedy 1993). Site preparation can increase survival and improve early growth of hardwood planting stock (Baker and Blackmon 1978, Ezell and Catchot 1998, Russell et al. 1998). The wide array of conditions presented by former agricultural fields precludes generic prescriptions for site preparation treatments.

Appropriate site preparation for a given tract can only be determined by considering the landowner's objectives and the condition of the field to be planted. For fields in crop production just prior to planting, site preparation is often omitted on public land. Private landowners, however, may have management objectives that make it desirable to break-up a hard pan or compacted soil, broadcast a pre-emergent herbicide application for weed control, or incorporate fertilizer into the planting site. Fertilization, for example, has been shown to consistently boost growth of hardwood reproduction on former agricultural sites, because long-term agricultural production significantly depletes soil organic matter and associated nutrients (Francis 1985, Houston and Buckner 1989). Such practices are common if fiber production, timber production, or carbon sequestration are primary management objectives (Kennedy 1981a, Joslin and Schoenholtz 1998, Thornton et al. 1998, Yeiser 1999). Site preparation also has merit where other objectives target early stand growth and development.

Multiple-pass disking has been used effectively in the LMAV to break up dense sod, improve soil aeration, and promote water infiltration (McKnight 1970, Baker and Blackman 1978, Kennedy 1990). Subsoil or deep plowing to 40 to 50 cm is effective in breaking plow pans that may develop following years of cultivation. Deep plowing is a standard prescription generally necessary for establishing fast-growing species such as eastern cottonwood (McKnight 1970,

Stanturf et al. 2001b); it improves aeration and allows regeneration to exploit a greater soil volume.

Fields removed from cultivation for more than a year prior to planting will present a range of herbaceous and woody vine, shrub, or tree competition depending on the length of the uncultivated period and the rate of succession. Site preparation to control advance vegetation prior to planting can be accomplished with mechanical or chemical methods.

Chemical site preparation and dormant season weed control applications currently being developed show promise for relatively inexpensive early control of herbaceous weeds in hardwood plantations (Ezell 1995, Ezell and Catchot 1998, Ezell 1999, Ezell et al. 1999). Chemical site preparation offers the forester an ability to apply weed control during periods when site conditions prevent use of mechanical practices. Herbicide efficacy can be improved by first mowing or burning the field and allowing for a uniform regrowth of vegetation before herbicides are applied (Miller 1993).

Mowing is commonly used for site preparation in the LMAV on afforestation projects sponsored by governmental cost-share programs. This practice improves planter access on afforestation sites which have not received cultivation for several years, but mowing probably does little to reduce weed competition or herbivory (Houston and Buckner 1989). In fact, there is little evidence that mowing improves survival or growth of hardwood regeneration (Kennedy 1981b, Houston and Buckner 1989, Schweitzer et al. 1999). Kennedy (1981b) reasoned that mowing is ineffective for improving survival or growth of hardwood reproduction because it does not reduce competition by roots for soil water or nutrients. Prescribed burning, a more economical practice than mowing, can be used to improve planter access on afforestation sites. However, the use of prescribed fire requires training, and safety risks of smoke may limit the use of site preparation burning in some regions.

On some sites with saturated soils in the LMAV, site preparation is omitted in order to accommodate use of heavy equipment in machine planting.

Trafficability is improved, planting machines function better, and the risk of site damage is reduced if the surface is undisturbed. The trade-off is reduced growth because of competing vegetation and the increased risk of herbivory by small mammals.

#### **Planting Stock**

Size and quality of bare-root planting stock may determine establishment success and early growth of tree seedlings (Land 1983, Thompson and Schultz 1995). Because of differing growth rates, growth habit (i.e. indeterminant, semi-determinant, or determinant), and biomass accumulation patterns (Hodges and Gardiner 1993, Long and Jones 1993, Dickson 1994, Long and Jones 1996), bottomland hardwoods exhibit a wide range of interspecific seedling morphologies. Researchers working on bottomland hardwood regeneration early on identified desirable seedlings as those having a shoot length of 76 cm to 91 cm and a root-collar diameter of 6.5 mm to 9.5 mm or larger (McKnight and Johnson 1980, Kennedy 1981a). These criteria for a quality seedling were based on observations rather than experimentation. Definitive guidelines defining optimal seedling dimensions for bottomland hardwood species, particularly considering competing vegetation and flooding constraints, are unavailable.

Nursery culture and seedling handling practices can improve outplanting performance, especially on harsh sites. Proper top pruning of hardwood seedlings can significantly boost outplanting survival, from 3 percent to 42 percent (South 1998). Top pruning is thought to benefit the seedling by improving its root weight ratio, while it is of benefit to the planter because top-pruned seedlings are easier to handle. In addition to potential gains in survival, stimulated height growth of seedlings receiving moderate top-pruning

quickly compensates for the lost height of the pruned shoot (Adams 1985, Meadows and Toliver 1987). Moderate root pruning also can facilitate planting without significantly reducing survival or growth (Toliver et al. 1980). Yet, root pruning should be approached cautiously because excessive pruning will negatively alter root weight ratio and reduce carbohydrate reserves needed by the seedling to survive lifting and transplanting. Kennedy (1993) suggested that root systems of oak seedlings should be pruned to no shorter than 20 cm.

In addition to seedling size and handling practices, morphological traits including the number of first order lateral roots can have a profound effect on early survival and growth of hardwood seedlings (Thompson and Schultz 1995). Seedling out-planting performance has been linked with the inherited expression of first order lateral root proliferation (Kormanik 1986, Kormanik and Ruehle 1987, Kormanik 1989, Thompson and Schultz 1995, Kormanik et al. 1998). Fewer than 40 percent of oak seedlings lifted from nursery beds likely are suitable planting stock based on lateral root development (Johnson 1984, Kormanik and Ruehle 1987, and Clark et al. 2000). Though first order lateral root development is controlled strongly by genetics, their development can be increased by growing seedlings at relatively low nursery bed densities (Dey and Buchanan 1995). Most planting operations in the LMAV do not consider seedling morphology. Operational programs generally target a shoot length of 46 cm to 60 cm and a root-collar diameter of 9.5 mm as the minimal seedling size. Clearly, empirically tested information defining optimal seedling dimensions and morphological traits is needed to support efficient planting of a diverse array of bottomland hardwood species.

#### **Seed Sources**

Few studies have examined the transfer of seed within the hardwood region of the southern United States, but available evidence reveals provenance and family within provenance differences for survival and growth of common species including cherrybark oak (*Quercus pagoda* Raf.), American sycamore (*Plantanus*

*occidentalis* L.), and eastern cottonwood (Jokela and Mohn 1976, Land 1983, Greene et al. 1991). These studies suggest that survival and growth can be increased through provenance selections, but they also illustrate the hazards of indiscriminate seed transfer. For example, Dicke and Toliver (1987) observed a 30 percent range in survival within cherrybark oak families at age 5. In addition to concerns surrounding transfer of seed to different regions, establishing upland seed sources or ecotypes on bottomland sites may be problematic as well. For example, blackgum (*Nyssa sylvatica* Marsh.) ecotypes selected along a flooding gradient exhibited differing physiology, biomass accumulation patterns, and survival rates (Keely 1979). Contrary to this observation, short-term data (Yuceer et al. 1998) revealed no distinct differences in survival or growth of upland versus bottomland sources of cherrybark oak.

In practice, few afforestation foresters in the LMAV specify seed source constraints in purchasing agreements. This lack of quality control or use of certified seed in afforestation projects could potentially reduce establishment success, productivity, and forest health. Ideally, afforestation foresters should avoid transfer of seed collected from other regions and site types until adequate protocols for seed transfer are established. Morgenstern (1996) provided conceptual details for establishing seed transfer protocols for forest tree species. Interestingly, most other developed countries and larger U.S. companies in the forest industry have such protocols in place, as well as seed certification programs for the forests they manage.

#### **Seed and Seedling Storage**

Bare-root seedlings are the predominant stock type currently used in afforestation projects of the LMAV, accounting for 64% to date (King and Keeland 1999). Direct seeding has been applied on 29% of the afforestation area (King and Keeland 1999) and descriptions of direct seeding techniques and

operations can be found in Allen and Kennedy (1989) and Stanturf et al. (1998). Suitable techniques for collecting and storing seed of bottomland hardwood species are well documented (Schopmeyer 1974, Bonner and Vozzo 1987, Bonner et al. 1994). The remainder of this chapter will concentrate on practices and techniques appropriate for bare-root seedlings, although much of the discussion also applies to containerized seedlings and somewhat to direct seeding.

Bare-root seedlings should be lifted when dormant and directly transferred to storage under refrigeration at 0 ° to 2 ° C. To maintain seedling viability while in cold storage, seedling bags should receive ample ventilation and should be monitored for moisture content. Mobile cold-storage facilities are readily available for lease and most planting contractors or land managers who operate on a large-scale maintain cold storage facilities on the afforestation site during active planting operations. Such practices enable operators to maintain seedling dormancy and viability until time of planting.

### **Planting Seedlings**

Contractors operating in the LMAV use crews of both hand and machine planters, but establishment success rates between hand planting and machine planting is unknown (Russell et al. 1998). Nevertheless, observations indicate that either method can be sufficiently effective if experienced and conscientious personnel are overseeing the planting job (Gardiner et al. In Press). Techniques, advantages and disadvantages of each method are discussed below.

**Hand Planting**--Hand planting techniques originally employed to establish large-scale hardwood plantations were borrowed from technology used to establish conifer plantations. These practices generally were not applicable to hardwood plantation establishment because of the relatively large root systems characteristic of most hardwood seedlings, and the often-saturated condition of heavy clay alluvial soils. Hardwood seedlings typically have a

root system with the tap pruned to about 20 cm long and the laterals pruned to 10 cm to 15 cm. This requires using a planting tool with a blade at least 25 cm to 30 cm long by 15 cm to 20 cm wide. The type of dibble or planting shovel varies considerably among contractors and often the same tool will not work well on all sites due to soil characteristics, moisture conditions, or both. Hardwood seedlings should be planted with the apparent root-collar at least 2.5 cm to 5 cm below the surface of the soil. Burial of the root collar ensures that all lateral roots are sufficiently covered, and improves the sprouting potential of seedlings clipped by herbivores, primarily oaks.

Because of the time and care required to properly plant large seedlings in saturated soil, some contractors pay their planters by the hour rather than by the number of seedlings planted. A hand planting crew of 20 people can usually plant over 50 hectares per day (about 2000 seedlings per planter at 750 seedlings per hectare). This is quicker than a machine planting crew with one tractor. However, hand planting can be more expensive than machine planting; not only is it labor intensive, it also requires more administrative supervision and logistical planning to keep planting crews active.

**Machine Planting**--Machine planters for hardwoods are similar to conifer planters with modified packing wheels and coulters to allow for planting of larger seedlings. Most operators further modify stock planters to accommodate their specific planting needs. Planting machines are normally pulled by 4-wheel drive, rubber-tired tractors with a minimum rating of 175 horsepower. If soil conditions are favorable, machine-planting crews can more consistently plant large seedlings with well-developed root systems, and machine planting is generally not as expensive as hand planting based on cost per seedling. A single machine planter crew can plant about 6 to 8 ha per day if soil conditions are ideal. However, water saturated, heavy clay soil typical of some alluvial floodplain sites can hamper progress of machine planting, and the heavy equipment required for machine planting can damage afforestation

sites by creating ruts. Furthermore, if soil conditions are not ideal the slit created by the planting machine is difficult to close and voids are left in the lower reaches of the foot or coulter blade. The slit may reopen under dry conditions in the smectitic (expanding clay) soils of the LMAV, exposing seedling roots to desiccation. Machine planting also increases the minimal distance between planting rows, and it increases damage to growing stock if seedlings are being planted supplemental to partial failures.

Special problems are encountered in restoring permanently flooded sites. Because of loose, unconsolidated muck commonly found in deepwater swamps, machine planting is impossible and hand planting is difficult. Conner and colleagues developed a method for hand planting seedlings that involves pruning lateral roots and clipping the tap root, ending up with a spear (Conner et al. 1999, Conner et al. In Press). Root systems of seedlings grown in unsaturated soils in the nursery are not appropriate for saturated soils, as large portions of the root system die once planted. Since much of the original root system will die in saturated soil, pruning it prior to planting generally does not cause problems because the new root system that develops is appropriate for saturated soils. Planting the seedling "spear" is accomplished by holding it at the apparent root collar and pushing the seedling into the ground until the hand hits the soil surface. There are no tools to carry for digging holes, and filling in completely around the root is not a concern. In very loose soils, seedlings should be staked to keep them vertical.

Root pruning does not work well with all species. Baldcypress and water tupelo success rates have been high, but green ash (*Fraxinus pennsylvanica* Marsh.) and swamp blackgum (*N. sylvatica* var. *biflora* [Walt.] Sarg.) success has been poor. Green ash seemed to do well in the first one to two years after planting but died in succeeding years (Conner et al. 2000). The primary reason for poor performance of these species is that root systems never redeveloped in these saturated soils.

Hand-bagged seedlings and balled and burlap seedlings have been utilized for planting swamps (Conner et al. 1999). Balled seedlings established on the sediment surface sufficiently rooted into the sediment to withstand complete drying of surface water. However, there is no real benefit to using hand-bagged or balled and burlap seedlings, because root-pruned baldcypress and water tupelo seedlings cost less, are easier to plant, and show similar survival rates.

#### **Planting Job Inspections**

Planting jobs must be inspected by the contracting organization while operating to ensure that proper seedling handling, planting, and spacing is implemented. Problems in seedling viability resulting from improper handling or storage are nearly impossible to detect after the seedlings are planted. Inspection of the ongoing planting job allows for "real-time" correction of mistakes in planting and spacing. Walk-through inspections of the planting crew enables the forester to verify that seedlings are in good condition and not excessively root pruned prior to planting, and establishing fixed-radius plots behind the planting crew enables the forester to monitor planting density, seedling size, planting depth, and general quality. Some practitioners routinely sample one 80 m<sup>2</sup> plot for every 4 ha planted (Gardiner et al. In Press). However, seedling spacing should be considered when determining the size of fixed-radius plots; sampling intensity will depend on the area of the afforestation project, heterogeneity of the afforestation site, and consistency of the planting crew.

#### **Post-planting Cultural and Protection Practices**

Post-planting cultural and protection practices can boost seedling survival, early growth, and help maintain plantation integrity. Competition control is the primary means of increasing survival and improving seedling growth, but other practices such as irrigation and fertilization may expand in the future,

as demands for hardwood fiber increase (Kennedy 1981a, Kennedy 1981b, Francis 1985, Houston and Buckner 1989, Kennedy 1993, Schweitzer et al. 1999, Yeiser 1999). In spite of the demonstrated biological benefits of post-planting cultural practices, cost-benefit analyses seldom are conducted for such operations making it difficult to project their financial benefits. However, the additional costs of the practices discussed below may be justified if they prevent plantation failure as in the case of drought or herbivory, or if they significantly decrease rotation length as in the case of disking operations in short-rotation woody crops. In practice, few afforestation foresters prescribe post-planting cultural treatments unless fiber or timber production is a primary management objective, although other objectives could benefit from improved seedling vigor.

**Competition Control**--Competition control in hardwood plantations can be accomplished with mechanical methods, chemical methods, or with the use of mulch material. Mechanical methods include mowing and disking. As mentioned previously, hardwood reproduction generally does not respond to mowing treatments because mowing does not reduce belowground competition for soil water and nutrients (Kennedy 1981b, Houston and Buckner 1989, Schweitzer et al. 1999). Mowing may be useful only on sites where the forester wishes to set back development of invasive woody species competing with desired reproduction.

Disking is generally more effective than mowing in controlling competing vegetation, although costs are similar. Several bottomland species, including sweet pecan (*Carya illinoensis* (Wangenh.) K. Koch)), Nuttall oak (*Quercus nuttallii* Palmer), green ash, American sycamore, eastern cottonwood, and sweetgum, respond favorably to disking (Kennedy 1981b, Houston and Buckner 1989, Schweitzer and Stanturf 1999). In addition to increasing aeration and moisture infiltration into soil, control of competing vegetation with disking improves the nutrient status of hardwood reproduction thereby facilitating

improved growth (Kennedy 1981b). Disking produces gains in survival and growth and will accelerate stand development (i.e., quicker advancement to canopy closure and self-pruning). However, tree growth can be reduced when roots are pruned heavily by excessive or deep diskings (Schweitzer and Stanturf 1999).

Competition control can effectively increase growth of bottomland hardwood seedlings (Miller 1993, Russell et al. 1998), and herbicides may provide the most cost-effective means of controlling competing vegetation in relatively large, hardwood plantations. Several herbicide tank mixes suitable for use with bottomland hardwood species have been identified (Ezell and Catchot 1998, Russell et al. 1998, Ezell 1999, Ezell et al. 1999). However, most tank mixes are best suited for controlling grass and some broadleaf herbaceous species; and chemical technology is not available for controlling woody vines, shrubs or trees in established plantations. Chemical control of undesirable woody species can be attained only with directed applications of suitable herbicides with appropriate measures taken to minimize spray drift and contact with crop species (Miller 1993, Leininger and McCasland 1998). Sites occupied by resilient vine species, such as ladies'-eardrops (*Brunnichia cirrhosa* Banks), trumpet creeper (*Campsis radicans* (L.) Seemann), and peppervine (*Ampelopsis arborea* (L.) Koehne), may require two or more years of treatment before afforestation can be attempted. Increasingly, invasive exotic species are a problem, including such aggressive species as Chinese tallow (*Sapium sebiferum* (L.) Roxb.).

Mulching is generally more expensive and more cumbersome to apply than other methods of vegetation control, but it can provide long-term efficacy resulting in dramatic gains in survival and growth during the initial stages of stand development (Windell and Haywood 1996, Adams 1997). Limited research on bottomland hardwood species has demonstrated promising gains in early growth for mulched common persimmon (*Diospyros virginiana* L.), green ash, Nuttall

oak, cherrybark oak and water oak (*Quercus nigra* L.) (Adams 1997, Schweitzer et al. 1999). Several types of organic and synthetic mulches are commercially available, but ease of application, durability of the material, maintenance requirements, effectiveness, and cost should be considered when selecting an appropriate mulch material (Windell and Haywood 1996, Haywood 1999). Future use of mulches may increase on wetland sites not amenable to mechanical methods of vegetation control, or on other sites where herbicide use is restricted.

**Protection from Herbivores**---Control of herbaceous vegetation improves early survival and growth of seedlings, can modify herbivore use of old field habitats (Hamel et al. In Press), and may lead to reduced incidence of herbivory damage. Animal damage can range from mild with little effect on planted seedlings to severe in which high densities of herbivores decimate young tree plantations (Conner and Toliver 1990). Several mammals including white-tailed deer (*Odocoileus virginianus* Zimmerman), rodents (including *Sigmodon hispidus* Say and Ord), rabbits (*Sylvilagus* spp.), beaver and nutria (*Myocastor coypus* Molina) have been documented as primary damaging agents in bottomland hardwood plantations (McKnight 1970, Conner and Toliver 1990, Burkett and Williams 1998, Conner et al. 1999, King and Keeland 1999). Crayfish (*Procambarus clarkii* Girard) also can become a problem to seedlings planted in swamps when food sources are low. Scraping algae at the waterline by crayfish can girdle seedlings and cause tip die-back (Conner 1988).

Herbivory by beaver and nutria can severely restrict plantation establishment and may be most effectively curtailed through continuing management of habitat and populations. Aside from modification of habitat, which is primarily effective on rodents, herbivory may be discouraged with seedling protection or herbivore eradication practices. Eastern cottonwood plantations have been fenced to exclude deer predation (McKnight 1970, Stanturf et al. 2001b).

Seedling shelters are effective for increasing survival where herbivory limits establishment (Graveline et al. 1998, Strange and Shea 1998, Conner et al. 1999). Several styles of shelters are available commercially, and selection of style and size will depend on several factors including the size of seedlings in need of protection, expected herbivory type, costs, and assembly and installation requirements (Windell 1991). In addition to protection from herbivores, some tree shelters also provide a favorable microclimate for improved early growth of tree species (Tulley 1985, Schweitzer et al. 1999). Shelters serve to facilitate growth by moderating the light environment, reducing seedling transpiration rates, increasing temperature, and increasing carbon dioxide availability (Tulley 1985, Windell 1991). Early gains in height growth are due to temporary shifts in biomass accumulation and are not maintained after seedlings emerge above the shelters (Mullins et al. 1998, Clatterbuck 1999). The primary drawback of using shelters is the high cost associated with purchasing the shelter material, installation, maintenance, and removal from the field. In addition, shelters are easily knocked-down or swept away by flowing floodwaters. These drawbacks will typically limit use of shelters only to sites where the expected herbivory is severe.

**Protection from Other Damaging Agents**--Other protection practices in established plantations include control of insect or disease pests, fire prevention and suppression, and floodwater management. Insects and diseases can reduce the health of plantations and render planted stock vulnerable to other forms of stress. For example, control of several pests including the cottonwood leaf beetle (*Chrysomela scripta* F.) and the cottonwood borer (*Plectrodera scalator* Fab.) may be necessary in young eastern cottonwood plantations being cultured for rapid biomass production (Solomon 1985, Stanturf et al. 2001b). Damage by insects or diseases can be reduced through preventative practices such as selection of resistant seed sources or clones (Cooper et al. 1977, Nebeker et al. 1985, Kellison 1994), or by eradication of the pests through direct cultural, chemical or microbial techniques (Solomon

1985, Solomon et al. 1997). Several handbooks developed by Solomon and his colleagues provide useful descriptions of major insect pests and diseases of common bottomland tree species including cottonwood, green ash, sycamore and the oak species (Morris et al. 1975, Solomon et al. 1993, Solomon 1995, Solomon et al. 1997, Leininger et al. 1999).

Wildfire can destroy young hardwood plantations and reduce stem quality of stump spouts. Kennedy (1993) suggested maintenance of fire lanes around all plantations as a precautionary measure against wildfire. If fire sweeps through a hardwood plantation, the site will have to be inventoried to determine the extent of damage and the next course of action needed for management of the plantation.

Though most bottomland hardwood species exhibit some level of tolerance to anaerobic soil conditions, long-term flooding or inundation during the growing season can harm all but the most flood tolerant species (Baker 1977, Hook 1984). Monitoring and control of floodwater depth and duration are necessary if survival of young hardwood seedlings is at stake. Where flooding is desirable for creation of waterfowl habitat (e.g., greentree reservoirs), removing floodwater prior to the active growing season will usually reduce the potential for flooding stress on seedlings. Additionally, well-managed impoundments could improve seedling survival or growth by increasing soil moisture availability during the potentially dry summer months (Broadfoot 1967).

#### **Post-planting Survival and Growth Monitoring**

Planting success can only be determined by comparing seedling survival and growth to an *a priori* definition of success. Sampling intensity, timing, and measurement interval are determined in part by the landowners management objectives, the type of plantation (e.g. pure versus mixed species), availability of preexisting data and costs of acquiring new data (Curtis

1983). However, prior to post-planting assessments, baseline information on plantation establishment is vitally important to the afforestation forester. Information such as seed source, seedling size and condition, seedling lifting date, shipment and storage history, soil and atmospheric conditions during planting, planting methods employed, planting contractor, site preparation activities, and planting date, can be used to identify the source of problems or successes. Post-planting assessment and monitoring techniques vary widely among landowners and public agencies, but they may often include sample transects, permanent sample plots, permanent photo-points to document stand development, and periodic aerial photography.

#### **Planting Density and Species Mixtures**

Planting density is an important decision because of the effect it has on meeting landowner objectives and minimizing costs. The simplest approach is to determine an adequate stocking level at some point in time, then calculate the initial density needed to achieve that target given expected survival. For example, the Wetlands Reserve Program (WRP) is a federal incentive program in aid of farmers planting hardwoods on low-lying cropland (Stanturf et al. 2000). The WRP survival target is 309 stems per ha at age three, which is too few for timber production and may be inadequate for forested wildlife habitat. Nevertheless, it is the target stocking level. For Nuttall oak, the most commonly planted oak species in the LMAV; an average operational survival rate for planted seedlings on sites with minimum site preparation is 60 percent. Thus, 515 seedlings per ha should be planted to meet the target of 309 stems per ha at age 3. For other oak species, however, survival is typically lower, 30 percent to 40 percent. So planting densities should be adjusted accordingly. If inexperienced planting crews are used or supervision is inadequate, survival rates will be below operational benchmarks, resulting in significant failures (Stanturf et al. 2001a).

#### **BENEFITS OF RESTORATION**

The benefits of restoration usually are identified in terms of agency priorities or social benefits; seldom are the diverse objectives of landowners recognized. In most market economies where rights and obligations of ownership rest with private landowners, what is appropriate for public land may not be the most attractive restoration option for private landowners (Stanturf et al. 2001a). Nevertheless, there can be considerable overlap in the expected benefits to society and the affected landowner. The array of possible landowner objectives can be illustrated with a limited set of management scenarios from the LMAV (Table 3). For simplification, three scenarios are presented: short-rotation management for pulpwood or fuelwood; a longer-rotation typical of management for sawlog production which is suitable for wildlife that requires complex vertical structure, such as certain Neotropical migratory songbirds (Hamel et al. In press) and an option termed "green vegetation" which is essentially the no management scenario. In the green vegetation scenario, species composition and stand structure are secondary concerns to removing land from active agriculture. This option meets the objectives of federal programs such as the Wetlands Reserve Program (Stanturf et al. 2001a). It may also provide habitat conditions for certain wildlife species typical of old fields that otherwise would not occur on the landscape (Hamel et al. In press).

Benefits are comprised of financial, recreational, and environmental outcomes. Because cash flow is important to many landowners, and the adjustment from annual to periodic income is often cited as a barrier to afforestation, financial benefits are considered as both short-term and long-term. Recreational benefits are hunting (typically for white-tailed deer, wild turkey (*Melagris gallapavo*), and waterfowl) and non-consumptive benefits such as bird watching or hiking. Environmental benefits are separated into conservation practices (such as those installed to control soil erosion,

protect water quality, or enhance wildlife habitat) and land retirement, where there is no on-going management activity.

### **Financial Benefits**

Financial returns from active management are substantial relative to the green vegetation scenario. Sawlog rotations of high-value oak and green ash are expected within 60 years to 80 years, with the first commercial thinning beginning in 20 to 30 years. Short-term financial returns from growing pulpwood-sized eastern cottonwood in the LMAV are realized within 10 years of afforestation (Stanturf and Portwood 1999). Short-term financial returns are low from plantations of other species. Nevertheless, other species can be combined with cottonwood in the nurse crop technique to produce income for one or two pulpwood rotations, hence the medium rating. The green vegetation scenario, typified by WRP plantings, provides no long-term income because timber management is unlikely, given the understocked stands that will develop (Stanturf et al. 2001a). In the short-term, there is income from the one-time easement payment made to the landowner (Stanturf et al. 2000).

Other income can be realized by some landowners from hunting leases and potentially from carbon sequestration payments. In the Mississippi portion of the LMAV, hunting rights are leased for \$7.50 to \$12.35 per ha per year. There is also a potential for substantial income to landowners from credits from carbon sequestration (Barker et al. 1996). While there is considerable uncertainty over accounting for carbon credits under the Kyoto Protocol, there seems to be agreement that afforestation will be eligible for offset credit (Schlamadinger and Marland 2000). Current projections in the United States for the value of a carbon credit are on the order of \$2.72 to \$4.54 per Mg of CO<sub>2</sub> sequestered, but the value is much higher in Europe. In Norway, for example, there is already a carbon tax on gasoline equivalent to \$49 per Mg

CO<sub>2</sub> (Solberg 1997). Estimates from economic models suggest that a carbon tax of \$27 to \$109 per Mg CO<sub>2</sub> would be necessary to stabilize global emissions at the 1990 level (Solberg 1997). Under these conditions, growing biomass for fuel would become an attractive alternative to fossil fuel because biofuels have no net impact on global carbon levels. At some time in the future, landowners in the LMAV may want to optimize carbon sequestration and biofuel benefits by planting black willow (*Salix nigra* Marsh.) on soils too wet for eastern cottonwood.

### **Recreational Benefits**

The primary recreational benefits assumed in the examples are from creating and enhancing wildlife habitat. Not all wildlife species require the same kind of habitat, so for simplicity the expected benefits can be separated into recreational hunting by the landowner (rather than lease fees) and non-consumptive wildlife activities, such as bird watching or simply the existence value of wildlife to the landowner. Most species hunted in the LMAV benefit from a range of forest conditions and expected benefits are high in stands managed for pulpwood or sawlogs. Low expected value is derived from the kind of open stands likely to develop from the green vegetation scenario (Allen 1997, King and Keeland 1999). Neotropical migratory birds and other birds are not uniform in their habitat requirements (Hamel et al. In press), but some will benefit from the kind of early successional habitat typical of short-rotation stands (Twedt and Portwood 1997) as well as early successional herbaceous fields of the green vegetation scenario. Species of concern are of two kinds, those requiring early successional herbaceous vegetation and those found in the kind of complex vegetation structure found only in older stands, which the sawlog rotation may develop in time (Hamel et al. In press). Birds that use intermediate conditions of stand development are likely to occur in developing stands for which the intended management purpose is sawtimber

production.

### **Environmental Benefits**

Water quality benefits of afforestation accrue from reducing soil erosion (Joslin and Schoenholtz 1998), and filtering, retaining, and assimilating nutrients and farm chemicals from surface runoff and groundwater (Huang et al. 1990). Among key wetland functions, biogeochemical processes such as filtration have the highest societal value. This function requires flow-through hydrologic regimes typical of riverine forests. However, typical afforestation stands in the LMAV are not subject to the flow-through hydrologic pulse of a riverine system, and their ability to filter nutrients will be limited (Lockaby and Stanturf In press).

Afforestation of former agricultural areas that are protected from flow-through systems (i.e. flooding) by dikes, ditches, and other barriers cannot be considered restoration in a complete sense unless some semblance of flow-through processes are also restored. Large-scale restoration of natural, riverine flooding regimes is rarely feasible. This limitation of afforestation activities has been recognized previously (Allen 1997, King and Keeland 1999). Suggested remedies have included plugging drainage ditches or building water control structures on portions of the afforested sites so that controlled flooding can be induced in much the same way that it is applied within greentree reservoirs. On public land such as national wildlife refuges and national forests, relatively large areas have been restored in this fashion as greentree reservoirs, moist soil management units, or permanent water bodies. In addition, it is common for some flooding to occur on lower lying portions from accumulation of precipitation. Although afforested sites may have water control structures that produce standing water, and appear to function as depressional wetlands, they differ significantly from basin wetlands in their functioning (Lockaby and Stanturf In Press). Because these quasi-depressional

afforested systems remain isolated from riverine influences, they contribute little to biogeochemical filtering or to the export of particulate or dissolved organic carbon to aquatic systems.

Improved water quality can be derived from forested riparian buffers. Planted forested buffer strips in an agricultural landscape are uncommon, although several studies have examined the filtering action of natural forested riparian zones (Lowrance et al. 1983, Todd et al. 1983, Lowrance et al. 1984a and b, Peterjohn and Correll 1984, Lowrance et al. 1986, Cooper et al. 1987, Cooper and Gilliam 1987). These studies were summarized by Comerford et al. (1992) who concluded that buffer strips are quite effective in removing soluble nitrogen and phosphorus (up to 99 percent) and sediment. The efficiency of pesticide removal by forested buffer strips has been examined in some environmental fate studies, which concluded that buffer strips 15 m or wider were generally effective in minimizing pesticide contamination of streams from overland flow (Comerford et al. 1992). Recently, forested buffer strips in the LMAV became attractive financially to the landowner by a new incentive program (Continuous Signup/Conservation Reserve Program), which allows landowners to plant fast-growing plantation species including Eastern cottonwood.

The Environmental Protection Agency has identified the Yazoo-Mississippi basin as an area of significant concern for surface and ground water quality. Although surface water runoff in the LMAV contributes only 20% of the nitrate loading implicated in the expansion of the hypoxic zone in the Gulf of Mexico, the EPA is expected to focus significant resources on the LMAV to improve water quality. Policy alternatives under consideration include reducing nitrogen use by 20%-40% and converting agricultural land to forests in an effort to restore and enhance natural denitrification processes (EPA 1999). The assumption is made that restoration (afforestation) of bottomland hardwood forests will reduce

nutrient export into the Gulf. This will be true to the extent that a potential source of nutrients will be reduced by changing land use from row crop agriculture to forests (Thornton et al. 1998). However, the restored system will play at most a small role as a nutrient filter unless it is hydrologically linked to a riverine system. Thus a greater benefit, in terms of nutrient filtration, would come from afforestation of the active floodplains of small rivers throughout the basin, and from buffer strips planted along drainage ways (Castelle et al. 1994, Castelle and Johnson 2000). Nevertheless, the relative effectiveness of forest versus grass buffers in nutrient filtration remains uncertain.

#### **EFFECTS OF RESTORATION ON WILDLIFE AND FISH**

Afforestation is assumed to benefit "wildlife" (Wesley et al. 1976, Weaver et al. 1990, Weaver and Pelton 1994, Boyle 1999, Cannell 1999b, Helmer 1999, Willoughby and McDonald 1999). On the other hand, certain native wildlife and grazing animals can hinder afforestation efforts (Houston 1991, Anderson and Katz 1993, Niyaz et al. 1999). Recent assessments of afforestation of agricultural lands in the LMAV have stressed the importance of rapidly attaining the physical structure and stature of forests (Schweitzer et al. 1997). Such rapid afforestation implies rapid accumulation on the landscape of the physical structure and stature of forest. Rapid development of vertical forest structure is implicit in the environmental (Joslin and Schoenholtz 1998) and economic (Scholtens 1998, Pande et al. 1999) analyses of afforestation. Rapid afforestation is also an essential feature of programs directed toward carbon sequestration benefits (Cannell 1999a, Chang ChingCheng 1999).

Vegetation structure is an important determinant of bird species occurrence and community composition (James 1971, DeGraaf 1987, DeGraaf et al. 1992). Bird association with elements of vegetation structure, as trees, shrubs, herbaceous vegetation, and combinations, has been categorized (Hamel 1992).

Afforestation combines elements of vegetation structure in ways not necessarily usual in secondary succession, such as tall cottonwood trees and herbaceous vegetation with little woody understory.

Afforestation, particularly rapid afforestation, is likely to shorten the early successional period. Herbaceous dominated plant communities appropriate for wintering birds utilizing early successional habitats consequently will persist for shorter periods if land is afforested rather than allowing natural succession. Rapid afforestation provides winter habitat for a number of species quickly (Wesley et al. 1976, Twedt and Portwood 1999), at the expense of a few high priority species found in early successional habitats. Less rapid restoration of forests in the LMAV may provide demonstrable, albeit unintended, benefits to birds that winter within afforested sites in early successional stages. The early successional species that specialize on herbaceous vegetation are of higher than average conservation priority among the birds found in afforestation areas (Hamel et al. In Press).

Forested stream buffer zones provide multiple benefits to stream fishes (Angermeier and Karr 1984, Gregory et al. 1991). Indirect benefits include reduction of sediment and nutrient inputs (Lowrance et al. 1984b), stabilization of stream banks, and moderation of water temperature extremes (Gregory et al. 1991), factors that can affect fish productivity, physiology, reproduction, and community composition (Matthews 1987). More directly, organic matter input into streams as leaves and in-stream wood provides the primary energy source for aquatic macroinvertebrates (Wallace et al. 1997), which form the food base for most stream fishes. In sandy Coastal Plain streams, debris dams and large wood greatly increase macroinvertebrate production (Benke et al. 1984, 1985, Smock et al. 1989), promote channel stability, and increase habitat complexity for fishes (Shields and Smith 1992). Even modest densities of in-stream wood in channelized or incised, sand-bed streams can shift fish communities from those associated with

colonizing stages to those of intermediate or stable stages (Warren et al. In Press).

Many fishes of the southern United States use inundated forests for spawning, nursery, and foraging areas (Guillory 1979, Finger and Stewart 1987, Ross and Baker 1983, Baker et al. 1991, Killgore and Baker 1996, O'Connell 2000). As in planting prescriptions for afforestation, hydrology is critical for fishes (Finger and Stewart 1987, Hoover and Killgore 1998). Long-duration flooding in late-winter to early spring is especially important for spawning but even short-term flooding of forests can provide fishes with important energy from aquatic and terrestrial invertebrates (Ross and Baker 1983, Slack 1996, O'Connell 2000). Flooded forests provide nursery habitat to both wetland fishes and those of streams and rivers (Killgore and Baker 1996, Hoover and Killgore 1998). In the LMAV, flooded forest habitats support higher larval fish abundance of sport, commercial, and non-game fishes than flooded agricultural fields (recently cropped and fallow) (Hoover and Killgore 1998).

Large-scale afforestation of the LMAV emphasizing flood-prone agricultural areas and stream buffer zones could dramatically affect productivity and diversity of fish and other aquatic communities (Junk et al. 1989, Smock 1999, Magee et al. 1999). Within the LMAV, seasonally inundated forest habitat is greatly diminished (Hoover and Killgore 1998), most stream and river systems are highly modified (Shankman 1999), and most streams lack forested buffer strips. Nevertheless, southern bottomland hardwood wetland habitats support at least 45 characteristic fish species (Hoover and Killgore 1998) and in drainages dominated by bottomland forest, most stream and river fishes occur in and actively use inundated forest habitat (Baker et al. 1991). As noted, afforestation in the LMAV now emphasizes small low-lying tracts embedded in a matrix of agriculture. Future emphasis on forested riparian stream buffer strips that connect stream and river systems to afforested tracts is a primary consideration to maintain and enhance fish and aquatic communities (Gore and

Shields 1995).

## CONCLUSION

The LMAV is currently experiencing extensive afforestation of former agricultural fields on sites which historically supported bottomland hardwood forests. The current pace of afforestation may be maintained through the next decade, resulting in the establishment of hundreds of thousands of ha of bottomland hardwood plantations. Hardwood plantations established on former agricultural fields in the LMAV comprise a diverse suite of plantation types ranging from single-species to mixed-species plantings. Single-species plantations, or monocultures, are often the most efficient plantation type for optimizing production of a single output, e.g. fiber production or soil amelioration. Establishment of single-species stands allows for efficient application of cultural practices, predictable stand development patterns, and more predictable yields (Smith 1986). In the LMAV, the native "soft" broadleaf species that exhibit indeterminate growth patterns are well suited for culturing in this manner. Eastern cottonwood plantations, which are cultivated for high quality, printing fiber, are the most extensive example of single-species plantations cultivated in the LMAV (Krinard and Johnson 1980). Single-species plantations are not well suited for production of high quality sawtimber because most valuable species such as the oaks generally develop their highest vigor and quality in stands providing inter-specific competition (Lockhart and Hodges 1998).

Mixed-species plantations can include various arrangements of multiple species in true mixtures or intercropping mixtures (Goelz 1995a). Potential benefits of mixed-species stands versus single-species stands can include increased pest resistance in the stand, increased productivity or yields if the stand is vertically stratified, increased product diversity, improved quality of crop trees, and increased canopy species diversity (Smith 1986, Goelz 1995b). True mixtures generally consist of randomly or systematically assigned species

combinations established at the same time. Some mixed plantations are established with species of similar growth rates and developmental patterns (Goelz 1995a), but most successful mixtures require establishment of species that will stratify within the forest canopy (Smith 1986, Clatterbuck et al. 1987, Clatterbuck and Hodges 1988, Lockhart and Hodges 1998). Stand development processes in well-designed species mixtures will track development patterns observed in natural mixed stands (Lockhart et al. 1999). Most current afforestation practices under governmental cost-share programs attempt to establish true species mixtures as a means of providing stand-level species diversity. Unfortunately, many of these plantations are established without consideration for the developmental trajectories and competitive interactions of the individual species comprising the mixed plantation (Lockhart and Hodges 1998) and probably will not meet diversity objectives.

Scientists in other regions have demonstrated the value of fast growing, single-species plantations as catalysts for rehabilitating degraded forest ecosystems (Parrotta et al. 1997). In this role, plantations offer the potential to quickly accumulate above and below ground biomass and thereby facilitate soil stabilization, increased soil organic matter, nutrient or water holding capacity, development of an understory microclimate that promotes establishment of native species, and development of habitat for native fauna (Parrotta 1992, Fisher 1995, Mapa 1995, Lugo 1997, Parrotta 1999). Intercropping mixtures are created by establishing species that exhibit very different growth rates. Such mixtures may be used to provide different products such as a commercial timber species intercropped with a nitrogen-fixing species (Goelz 1995a).

Scientists and land managers working in the LMAV have developed an intercropping scheme using the early successional eastern cottonwood as a nurse species for the slower growing disturbance-dependent Nuttall oak (Schweitzer et al. 1997, Twedt and Portwood 1997). Potential benefits of the

eastern cottonwood - Nuttall oak intercropping could include rapid rehabilitation of soil quality, rapid development of vertical structure for animal habitat, early financial return on the restoration investment, and development of a favorable understory environment for establishment of oak seedlings and other native woody species. Intercropping systems show great potential for providing multiple ecological and landowner benefits in the LMAV.

Understandably, afforestation efforts have concentrated on establishing the dominant forest overstory trees, and little is known about the development of understory plants (Stanturf et al. 2000). In addition to vegetative restoration, there may be a need to restore microtopography, especially in areas where the original ridge and swale topography was leveled for agriculture. This is an expensive proposition (King and Keeland 1999) and as yet, the actual benefits of these practices are unknown. Nevertheless, such efforts would increase species diversity and result in restoration that is more complete.

Forest restoration, in the broad sense, is widespread. Similar challenges face foresters attempting large-scale restoration, and there are no easy answers. Simply put, the questions are what to do, how to do it, how to pay for it, and what benefits can we expect? Several fundamental components of afforestation are generally lacking in most regeneration practices currently performed in the LMAV. Developing some of these missing components will require additional research, but others will require only an extension of current knowledge or application of conservation principles. Incorporating silvicultural and ecological principles into public and private restoration activities will provide landowners, natural resource managers, and the general public better methods for evaluating success of these afforestation activities, and should improve afforestation efficiency, ecosystem health, and resource sustainability.

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Table 1. Forest restoration planned on former agricultural land by federal and state agencies in the Lower Mississippi Alluvial Valley, United States.<sup>1</sup>

Program	Agency <sup>3</sup>	Area (ha) <sup>2</sup>		
		1995	Planned To 2005	Total
Wildlife Refuges	USFWS	5,174	10,004	15,178
Wetland Mitigation	COE	2,024	9,704	11,729
State Agencies	MS, LA, AR	13,506	40,516	54,022
Wetlands Reserve Program (WRP)	NRCS	53,021	47,773	100,795
Total		73,725	107,997	181,724

<sup>1</sup> Adapted from Stanturf et al. 2000.

<sup>2</sup> Estimates furnished by participants at the Workshop on "Artificial Regeneration of Bottomland Hardwoods: Reforestation/Restoration Research Needs", held May 11-12, 1995 in Stoneville, Mississippi.

<sup>3</sup> USFWS=U. S. Fish and Wildlife Service; COE=U. S. Army Corps of Engineers; MS=Mississippi; LA=Louisiana; AR=Arkansas; NRCS=U. S. Natural Resources Conservation Service, formerly Soil Conservation Service.

Table 2—Examples of forest restoration efforts in various parts of the world.

Type of restoration	Region	Former condition	Restored condition
Afforestation	Lower Mississippi Alluvial Valley, USA <sup>1</sup>	Agriculture	Bottomland hardwoods
Afforestation	Nordic Countries <sup>2</sup>	Agriculture	Hardwoods, sometimes Norway spruce
Afforestation	Tropical Countries <sup>3</sup>	Agriculture	Exotic and native hardwoods
Afforestation	Venezuela	Cerrado	Caribbean pine
Afforestation	Iceland <sup>4</sup>	Eroded grazing land	Birch, lupine/birch
Reclamation	Everywhere	Mined land	Various
Reclamation	Asia <sup>5</sup>	Shrimp ponds	Mangrove
Reclamation	Ireland	Mined peatland	Sitka spruce, various hardwoods
Reclamation	India <sup>6</sup>	Saline and sodic soils	Eucalyptus spp., Acacia spp., other native spp.
Rehabilitation	Southeastern US <sup>7</sup>	Loblolly pine plantations	Longleaf pine woodlands
Rehabilitation	Interior highlands, Southeastern US	Shortleaf pine/hardwood forests	Shortleaf pine/bluestem grass woodlands
Rehabilitation	Northern Europe <sup>8</sup>	Norway spruce plantations	Oak or beech woodlands
Rehabilitation	England and Scotland	Spruce or pine plantations	Mixed woodlands

1 Allen 1990, 1997; Gardiner et al. In press; Hamel et al. In press; Newling 1990; Savage et al. 1989; Schweitzer et al. 1997; Sharitz 1992; Stanturf et al. 1998; Stanturf et al. 2000; Stanturf et al. In press; Twedt and Portwood 1997; Twedt and others 1999.

2 Madsen et al. In press.

3 Ashton et al. 1997; Chapman and Chapman 1999; Fisher 1995; Islam et al. 1999; Knowles and Parrotta 1995; Lamb and Tomlinson 1994; Ohta 1990; Otsamo 2000; Parrotta 1992; Parrotta et al. 1997.

4 Madsen et al. In Press; Sigurdsson 1977.

5 Burbridge and Hellin et al. In press.

6 Whalley 1988.

7 Walker and Boyer 1993.

8 Madsen and others et al. In Press.

Table 3--Financial, recreational, and environmental benefits expected from three afforestation scenarios common in the Lower Mississippi Alluvial Valley, southern United States

Scenario	Expected Benefit Level					
	Financial Short-term	Financial Long-Term	Recreational Hunting	Recreational Non-Consumptive	Environmental Conservation Practices	Environmental Land Retirement
Short Rotation (Pulpwood, Fuelwood)	High	High	High	Medium	Medium	No
Long-Rotation (Timber, Wildlife)	Medium	High	High	High	High	Medium
Green Vegetation	Low to No	No	Low	Medium	Medium	High

Figure 1—Estimated loss of global forest cover (Source: Krishnaswamy and Hanson 1999)

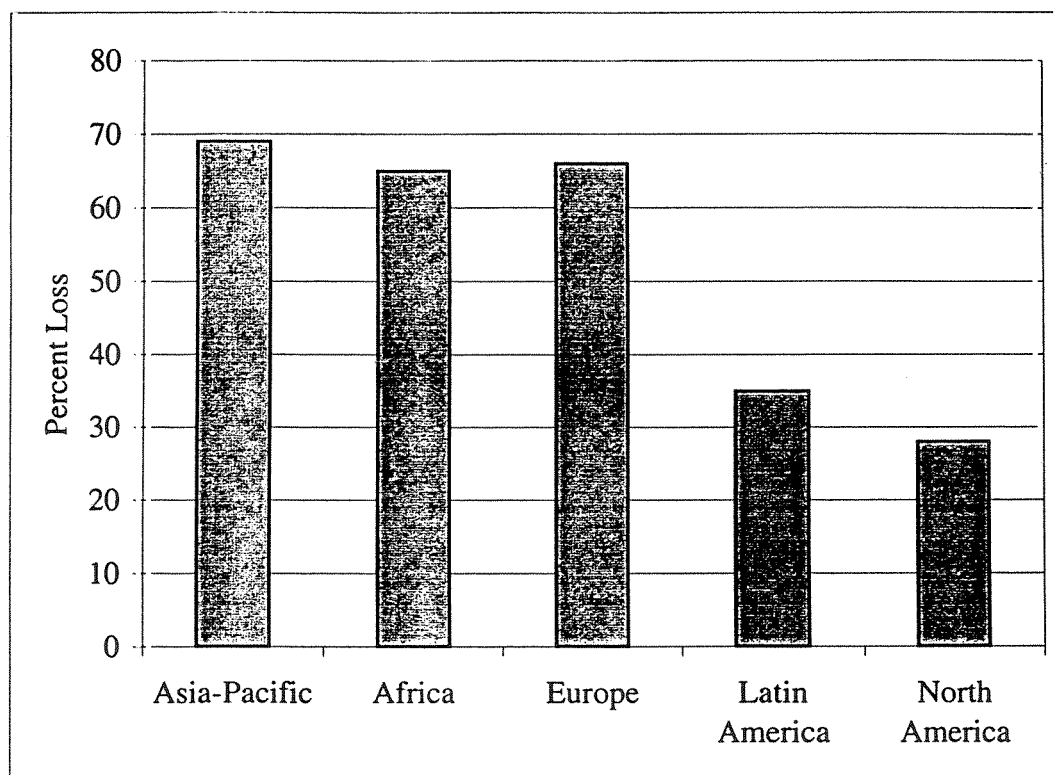


Figure 2. Extent of bottomland hardwood forests in the Lower Mississippi Alluvial Valley, from Pre-European contact (1492) to modern times (1990), with projections to 2020. Our estimate of forest cover prior to European contact assumes that Native American agriculture was at least as extensive as early colonial agriculture at around 1820. This is probably an underestimate. Our prediction of the area to be restored by 2020 is 1 million acres, roughly double the amount planned through 2005. (Sources: Stanturf et al. 2000)

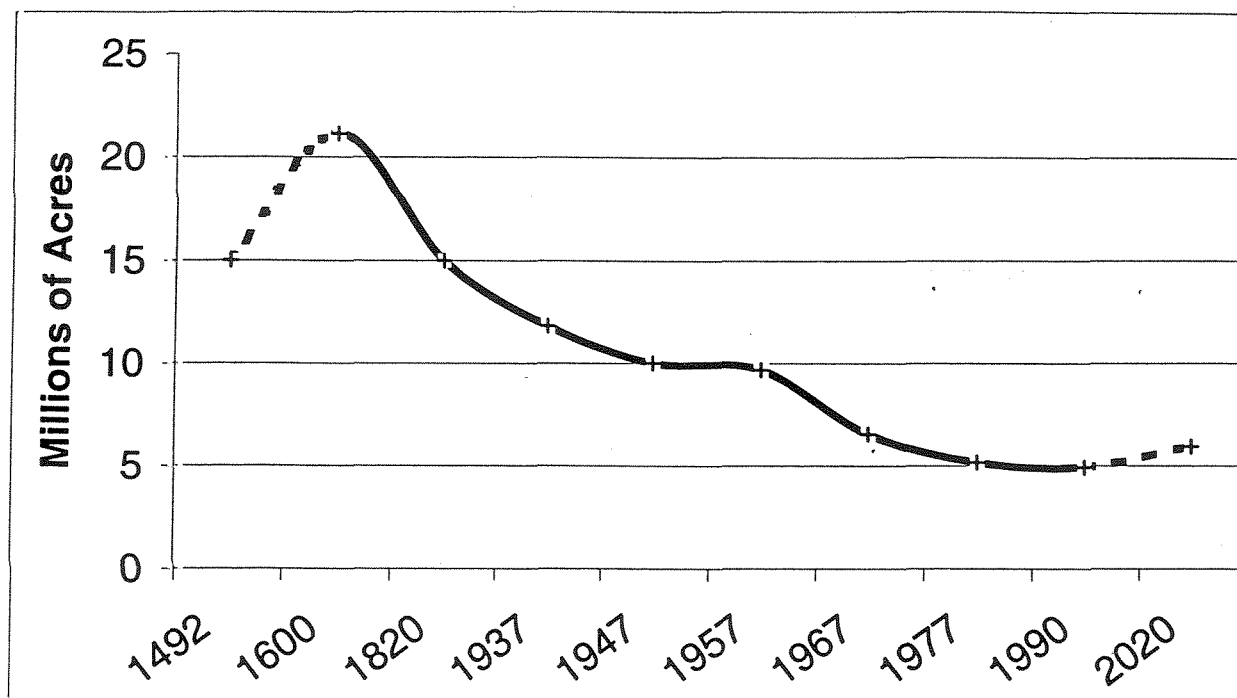


Figure 3--The terminology of forest restoration is best viewed in terms of land use as well as land cover change

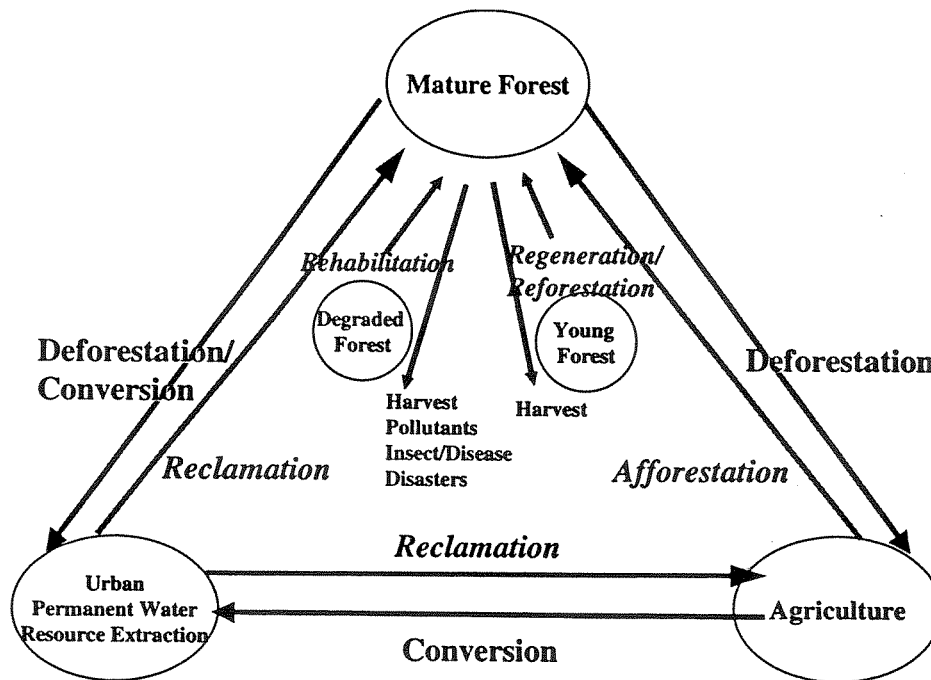


Figure 4. Bottomland oaks are the predominant choice of species for restoration plantings in the LMAV. (Source: King and Keeland 1999)

